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DESCRIPTION

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~~LINEAR INDUCTIVE TRANSDUCER~~

Technical Field

The present invention relates to a linear inductive transducer including electric windings with a primary winding and a pair of secondary windings, a magnetic core, for performing linear displacements relative to the electric windings, a pair of input terminals electrically connected to the primary winding and adapted for being electrically connected to a power supply unit, at least an output terminal electrically connected to the electric windings, the transducer being adapted for providing, through the output terminal, an electric signal indicative of the mutual position between the electric windings and the magnetic core.

The invention also relates to a linear inductive transducer including electric windings with a primary winding and a pair of secondary windings, a magnetic core, for performing linear displacements relative to the electric windings, a pair of input terminals electrically connected to the primary winding and adapted for being electrically connected to a power supply unit, and output terminals electrically connected to the electric windings, the transducer being adapted for providing, through at least one of the output terminals, an electric signal indicative of the mutual position between the electric windings and the magnetic core.

Background Art

Transducers with these characteristics, in particular of the Linear Variable Differential Transformer (LVDT) type have been known for a long time and utilized, among other things, in many measuring apparatuses for providing

electric signals indicative of the mutual position between mechanical parts. These transducers include a primary winding and a pair of secondary windings connected together in series opposition. The windings are wound on a substantially cylindrical bobbin at the interior of which a ferromagnetic core displaces along an axial direction. The primary winding is energized with a sinusoidal voltage and generates, at the ends of the secondary windings, induced voltages that vary as the axial position of the core changes. More specifically, the voltages induced in the secondary windings are equal and oppositely phased when the core is at an axially centered position. Thus, the total voltage at the free terminals of the secondary windings is null at said axially centered position, while its amplitude varies as the axial position of the core changes, and its phase changes in response to the sense of the axial displacement with respect to the centered position.

In U.S. Patent No. 4,386,467 there is disclosed a possible application of an LVDT in a comparator for checking a hole of a mechanical piece, in which the core and the transducer windings are respectively coupled to two mutually movable arms that carry feelers for touching diametrically opposite points of the hole.

Other types of inductive transducers are known as Half Bridge Transducers or HBT. These transducers include a pair of series connected windings, wound on a bobbin and energized with a sinusoidal voltage at the free ends thereof, and a ferromagnetic core axially movable within the bobbin. The output voltage is drawn at an intermediate point between the windings and its amplitude varies as the axial position of the core changes. The HBTs are broadly utilized in measuring devices, especially in simple devices like axial, or cartridge, heads, in consideration of the attributes of simplicity and inexpensiveness. Furthermore, unlike the LVDT transducers, the half bridge transducers have low output impedance values (e.g., 300 ohm as compared to 2000 ohm that represent a typical value for an LVDT),

thus the negative effects due to increased load impedance caused by the cable for the connection to the conditioning units are negligible. In fact, different cable lengths determine different load impedance values at the output of the transducer, and said load impedance in turn determines a variation in the amplitude of the output signal that increases the more the transducer output impedance is higher.

In a half bridge transducer the output impedance is relatively low since it is determined by the parallel of the impedances of the two windings, while it is definitely higher in a differential transformer transducer, where it is determined by the sum of the impedances of the two series connected secondary windings.

Another advantageous feature of the HBT in comparison with the LVDT, particularly in multiple applications in which the signals sent by a plurality of transducers have to be managed, is the possibility of utilizing -between each of the HBT and the conditioning unit- one electric connection wire less (three, as compared to four that are necessary for the differential transformer transducers) thereby simplifying the application.

A drawback of the HBTs is the poor sensitivity, i.e. the low ratio between the detected output signal variation and the associated core displacement. In a half bridge transducer, the sensitivity mainly depends on the geometric characteristics, more specifically on the ratio existing between the dimensions of the windings and those of the core, both generally imposed by the dimensions of the measuring device including the transducer. Hence, it is impossible to independently define the sensitivity and modify it for specific applications, for example in an application of a comparator as the one described in the formerly mentioned patent US-A-4,386,467. In fact, in this specific case, as there is an "arms ratio" (i.e., the ratio between the amount of displacement of the feelers and the amount of the associated mutual displacement between the

transducer's core and windings) that is known and generally differs from one, it can be advantageous to define the transducer sensitivity in order to take into account this known ratio, in this way simplifying the processings performed by the conditioning circuit.

Disclosure of Invention

An object of the present invention is to provide a linear inductive transducer that overcomes the disadvantages of the known transducers and, more specifically, enables to define its sensitivity regardless of the geometric characteristics, and none the less ensures a lower output impedance value and a lesser number of external electric connections with respect to the known differential transformer transducers.

This and other objects and advantages are achieved by a transducer according to claim 1.

A further object of the invention is to provide a linear inductive transducer that can present the functional charactersitcs of a differential transformer transducer, or a half bridge transducer, or a transducer of another type, by carrying out simple and rapid modifications.

This further object is achieved by a transducer according to claim 8.

Brief Description of the Drawings

The invention is now described in more detail with reference to the enclosed sheets of drawings, given by way of non limiting example, wherein:

figure 1 is a circuit diagram of an inductive transducer according to a preferred embodiment of the invention,

figures 2a, 2b and 2c are graphs that show the trend of some of the voltages at various points of the circuit

diagram of figure 1, taken at a plurality of mutual positions between the movable parts of the transducer,

figure 3 is a circuit diagram of an inductive transducer according to a different embodiment of the invention and a first possible configuration,

figure 4 is a circuit diagram of the transducer of figure 3, according to a second possible configuration, and

figure 5 is a circuit diagram of the transducer of figure 3, according to a third possible configuration.

The circuit of figure 1 schematically shows an inductive transducer **T** including first and second primary windings **1** and **3**, first and second secondary windings **2** and **4**, two input terminals **5** and **6** and an output terminal **7**. A magnetic core **8** can translate, with respect to windings **1-4**, in the **±X** direction.

A conditioning, or power supply and processing, unit **C** includes two sinusoidal voltage generators **11** and **13**, connected to ground (identified by reference number **12**) and in phase opposition to input terminals **5** and **6**, respectively, while signal processing means, connected to output terminal **7**, are schematically shown with a load impedance **15**.

A connection point **9** intermediate between primary windings **1** and **3** (that have the same number of turns **N1**) is connected to an end of one (**2**) of the secondary windings **2** and **4**, the latter being connected to each other in phase oppostion and having the same number of turns **N2**.

The dots **F** in the figure stand to indicate the phases associated with the voltages across the different windings **1-4** and the voltage generators **11** and **13**.

In an application in a comparator as the one shown in U.S. patent No. 4,386,467, core **8** and windings **1-4** are connected to the two movable arms carrying the feelers, respectively.

The operation of the circuit shown in figure 1 is as follows.

The primary windings **1** and **3** are energized with sinusoidal power supply voltages $\mathbf{Va}_{11}$ and $\mathbf{Va}_{13}$, that are identical and in phase oppostion, supplied by generators **11** and **13**. The voltage **Vo** at output terminal **7**, or measuring signal, is equal to the sum of two components: voltage **Vs**, present -with respect to ground- at intermediate point **9** between primary windings **1** and **3**, and voltage **Vs'** induced in the overall secondary windings **2** and **4**:

$$\mathbf{Vo} = \mathbf{Vs} + \mathbf{Vs'} \tag{1}$$

More particularly, the value of **Vs**, or unbalance voltage of the primary windings, is defined by

$$\mathbf{Vs} = (\mathbf{V1} - \mathbf{V3})/2 \tag{2}$$

where **V1** and **V3** indicate the voltages, or potential drops, across the primary windings **1** and **3**, respectively, while the value of **Vs'**, or unbalance voltage of the secondary windings, is defined by

$$\mathbf{Vs'} = \mathbf{V4} - \mathbf{V2} \tag{3}$$

where **V4** and **V2** indicate the voltages induced in the secondary windings **4** and **2**, respectively. When core **8** is at the central, symmetric position with respect to both the primary windings **1** and **3** and the secondary windings **2** and **4** shown in figure 1, both the components of the measuring signal **Vo** become null because the voltages at the ends of each of the primary windings **1** and **3** and each of the secondary windings **2** and **4**, respectively, have identical value:

$$\mathbf{V1} = \mathbf{V3} \tag{4}$$

$$\mathbf{V2} = \mathbf{V4} \tag{5}$$

Thus, in these conditions **Vo** = **0**. The displacement of core **8**, in response, for example, to the mutual displacement of the movable arms of the comparator including the transducer according to the invention, produces a variation in the reluctance of the magnetic circuits of windings **1** and **3**. The consequent inductance variation of the two windings produces two different voltage values **V1** and **V3** and thus an unbalance voltage **Vs** other than zero, according to formula (2).

The displacement of core **8** also varies the mutual inductance between the primary windings altogether considered **(1+3)** and each of the secondary windings **2** and **4**, differentially connected to each other. Therefore, because $V2 \neq V4$, unbalance voltage **Vs'** generated in the secondary windings differs from zero, according to formula (3).

The voltages **V2** and **V4** induced in the two secondary windings **2** and **4** by the overall primary winding **1+3** depend -at a specific position of core **8**- on a coupling coefficient **K**. More particularly, making the simplified hypothesis that primary windings **1** and **3** are equal and symmetric with respect to each other, as well as the secondary windings **2** and **4**, then

$$V2 = K \bullet V1 \tag{6}$$

$$V4 = K \bullet V3 \tag{7}$$

with

$$K = k \bullet n \tag{8}$$

where **k** varies depending on the transducer geometric features, and **n** is the turns ratio between secondary and primary windings: $n = N2/N1$.

The above hypothesis foresees the same **k** value in both the formulas (6) and (7) for the sake of simplification and making the substantial aspects of this invention clearer.

When the position of core **8** differs from the central symmetric one of figure 1, by substituting the formulas (2), (3), (6), (7) and (8) in (1), there results:

$$Vo = Vs\ (1 - 2 \bullet k \bullet N2/N1) \tag{9}$$

Thus, from formula (9) there results that output voltage **Vo** at terminal **7** has a value that, for displacements of core **8** of the same amount, varies among other things as the ratio of the turns varies $n = N2/N1$. As a consequence, contrary to what occurs in the known half bridge transducers, when the application requirements vary, the sensitivity can be set regardless of geometric considerations by choosing the appropriate turns ratio value **n**.

The figures 2a, 2b and 2c show the trend of the voltages hereinbefore mentioned in response to the various positions of core **8**. More specifically, figure 2a refers to the situation shown in figure 1 (core **8** is in a central and symmetric position) while figures 2b and 2c refer to situations according to which core **8** is displaced along **-X** and **+X**, respectively.

The trends of output voltage **Vo** of figures 2b and 2c show that, as the position of core **8** changes, the amplitude of the formerly mentioned voltage **Vo** varies, while the phase indicates the sense (**-X** or **+X**) of displacement of core **8** with respect to the central position of figure 1.

From the foregoing description and the figure 1 illustration, it appears that transducer **T** is connected to conditioning unit **C** by means of three conductors ending at terminals **5**, **6** and **7**, two being necessary for the power supply and one for the transmission of output signal **Vo**.

Another advantage of the transducer shown in figure 1 with respect to the known differential transformer transducers consists in the possibility of obtaining limited output impedance values. In fact, while the impedance value is determined, even in the arrangement shown in figure 1, by the sum of the impedances of the two secondary windings **2** and **4**, in this case it is possible to choose a small number of turns **N2** (and consequently low impedance values of the secondary windings **2** and **4**) without causing -contrary to the what occurs in the LVDTs- an unacceptable decrease in the transducer sensitivity. In fact, in the transducer according to the present invention, output signal **Vo** does not only depend on the transformer coupling, but, according to formula (1), it is the sum of two components. Thus, the choice of the appropriate turns ratio **n** (formula (9)) enables to achieve -in an extremely flexible way- the best possible balance among the required sensitivity and output impedance values.

According to an alternative to the herein illustrated and so far described embodiment, the primary windings **1** and **3**

are energized with a single sinusoidal voltage between terminals **5** and **6**, instead of the phase opposition voltages $\mathbf{Va_{11}}$ and $\mathbf{Va_{13}}$. In this case, voltage **Vs** -at the center position of core **8**- has a known amplitude value that differs from zero (for example, equal to half that of the energizing voltage). With respect to the previously described embodiment, this alternative does not present substantial differences, apart from the phase of output voltage **Vo**, that does not enable to immediately distinguish displacements in one or in the other sense with respect to the central position of core **8**.

The transducer **T'** shown in figures 3, 4 and 5 includes first and second primary windings **21** and **23** connected in series at a connection point **29**, first and second secondary windings **22** and **24**, five terminals **31**, **32**, **33**, **34** and **35** and a magnetic core **28** that can perform translation displacements with respect to windings **21-24**.

In the configuration shown in figure 3, transducer **T'** is substantially similar to transducer **T** of figure 1. In fact, in this configuration, terminal **33** (that ends at connection point **29**) and terminal **35** are short circuited, for example by means of a wire **36**. The voltage generators **11** and **13** of the conditioning unit **C**, shown in figure 1, are connected to terminals **32** and **34**, while output voltage **Vo** -substantially identical to the one attained with transducer **T**- is detected at the ends of load impedance **15** between terminal **31** and ground **12**.

In the configuration shown in figure 4, secondary windings **22** and **24**, ending at terminals **31** and **35**, are not connected to external units and thus are insulated. By providing in this configuration, too, a connection between voltage generators **11** and **13** and terminals **32** and **34**, it is possible to attain, by utilizing a suitable setting resistor **27**, an output voltage **Vo'** -at the ends of a load impedance **15'** between terminal **33** and ground **12**- that varies as the position of core **28** changes, according to the

well known functioning principle of a half bridge transducer or HBT.

Furthermore, in the configuration shown in figure 5, terminal **33** is insulated. A sinusoidal voltage generator **11'** is connected to terminals **32** and **34** for feeding a primary winding **21+23** that consists of both windings **21** and **23**, while an output voltage **Vo''** is detected, by utilizing a suitable setting resistor **30**, at the ends of a load impedance **15''** between terminals **31** and **35** (the latter being connected to ground **12**). Voltage **Vo''** varies as the position of core **28** changes, according to the well known functioning principle of a linear variable differential transformer or LVDT.

From the concise description of figures 3, 4 and 5, it appears that transducer **T'** is particularly flexible, since with a single structure it is possible to attain transducers of different types (LVDT, HBT or transducers of the new type described with reference to figure 1), and in each case achieve the type of transducer with the characteristics that best suit the specific application.

It is also to be noted that the setting resistors **27** and **30** are connected, respectively, to terminal **33** (insulated in the configuration of figure 5) and between terminals **31** and **35** (insulated in the configuration of figure 4). This enables to independently set the sensitivity for the HBT configuration (shown in figure 4) and LVDT configuration (shown in figure 5) on the same transducer **T'** and directly choose the proper configuration in the application phase, without the need of a further setting.

Transducers that include modifications with respect to what is herein schematically illustrated and so far described, for example in connection with the relative phases of the voltages at the ends of the different windings, also fall within the scope of this invention. In particular, by inverting the phase of the secondary windings (**2** and **4** shown in figure 1) with respect to that of the primary windings (**1** and **3**), formula (2) changes to **Vs = (V1 - V3)/2**

and, as a consequence, formula (9) changes to **Vo** = **Vs** (**1 + 2 • k • N2/N1**). Thus, this alternative choice enables to attain a higher sensitivity.

As previously discussed with reference to the known transducers (of the LVDT or the HBT type), the use of the linear inductive transducers in measuring and control devices and apparatuses is quite widespread and varied, and the comparator shown in the herein mentioned patent US-A-4,386,467 represents just one of the many possible applications for transducers **T** and **T'** according to the present invention.